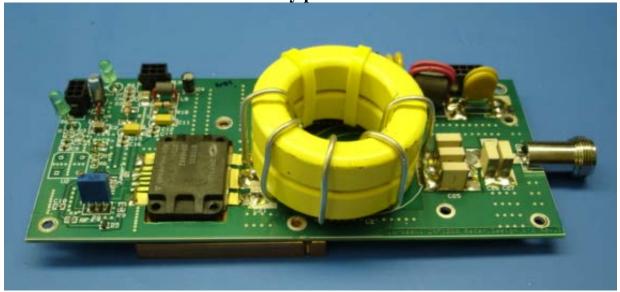


13.56 MHz, CLASS-E, 1KW RF Generator using a Microsemi DRF1200 Driver/MOSFET Hybrid

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The DRF1200/Class-E Reference design is available to expedite the evaluation of the DRF1200 Driver MOSFET hybrid. This Application Note or Reference Design Kit does not represent a finished commercial-ready design. It is only a teaching tool to demonstrate the capability of the DRF1200 under 50 Ohm, flat line condition. Each reference design kit has been verified to perform to the specifications of the application note. The application note contains a parts list, PCB layout and schematic that enables the user to facilitate any repairs resulting beyond its intended use. By purchasing the reference design kit the user takes full responsibility for repair and any modification. No warranties, repair or returns will be accepted.

The reference design kit contains lethal voltages and high power RF.
Use safety precautions.



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INTRODUCTION

This application note discusses the design procedures and test results for a 13.56MHz, 1KW, CLASS-E generator ideal for ISM applications. To achieve high efficiency and low cost, a Microsemi DRF1200 Driver/MOSFET was selected. The DRF1200 can generate over 1KW of output power and consists of a MOSFET driver, high power MOSFET and internal bypass capacitors in an air cavity flangeless package. The flangeless package was designed to optimize reliability, provide increased flexibility while still providing a low cost solution. A reference design board (DRF1200/CLASS-E) is available for purchase to facilitate the immediate evaluation of the principles of this application note.

To optimize efficiency performance, a CLASS-E RF generator was chosen. It is essential that care is taken to use adequate circuitry, clean PCB layout and good ground connections on the PCB to ensure proper output waveforms.

DESIGN CONSIDERATIONS

The following issues were considered in the design of a high efficiency, high power RF generator.

- a. CLASS-E operation for high-efficiency.
- b. Adequate output matching circuit. Matching tools were used to achieve the required power and efficiency.
- c. Parts that are capable of handling RF output of 1KW. This includes the bypass capacitor in the DC circuit and selecting a toroidal inductor and capacitors for output matching circuit.
- d. PCB designed for good ground connections, especially for the output matching circuit.
- e. PCB layout optimizing the isolation between power output and input signal generation circuit.

Table 1 shows the output achieved for this RF Power Generator.

Freq	Output Power	Voltage	Current	Efficiency
13.56Mhz	1KW	320V	3.7A	86%

Table 1. Key Specification

OVERALL CONCEPT

This high efficiency RF power generator uses a DRF1200 to minimize layout parasitics and optimize efficiency for CLASS-D and CLASS-E operation.

a. RF pulse generator circuit

The pulse oscillator and pulse control circuit is designed to create an ISM frequency of 13.56MHz and adjust the pulse width and phase according to circuit power requirements.

b. RF output matching circuit

The matching circuit was calculated with a RF matching software tool to maximize power transfer to 50 Ohm load. The circuit was then tuned using the inductor, capacitor and RF choke coil (RFC).

CIRCUIT DESCRIPTIONS

a. RF Pulse Generation

The Pulse generation circuit employs 13.56MHz TCXO and Flip Flop IC to adjust Pulse Width from 14nS to 35nS at the signal input of DRF1200. For this application, the pulse width is set at **15nS**. To minimize conductive EMI, it is crucial to use a good ground plane layout with respect to the signal lines.

b. RF Output Matching

The DRF1200 has a switching speed of 3~4nS, BVds of 1KV and Ids of 13A max. To achieve high-efficiency operation, the RF generator uses CLASS-E operation. At full power, the efficiency is approximately 86% at 13.56MHz. The MOSFET output capacitance was considered when tuning the external shunt capacitance to get the desired performance. See DRF1200 data sheet for output capacitance. The RF output matching circuit was designed using a RF matching tool and was optimized to achieve maximize power transfer to 50 Ohm Load. The output matching circuit is a series resistive circuit combined with a reactive circuit consisting of an "L" match Toroidal Inductor and Capacitors in series and shunt to ground.

c. DC Supply

The PS HV DC supply input circuit utilizes a RFC and by-pass capacitors to minimize interference with AC signal. The RFC was calculated to be approximately 1K Ohm impedance at 13.56MHz using 30 turns of 20AWG wire. The bypass capacitor should have a minimum 1KV rating.

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TEST REQUIREMENTS

a. Set-Up Diagram Power meter Spectrum Oscilloscope In. signal DRF1200 30dB Att. PS_1 PS_2

Figure 1. Test Set-Up diagram

b. Hardware and power sequencing requirements

- Cooling requirement: Testing is recommended to be performed using a water cooling system. If not available, should use enough heat sink to maintain continuous testing with sufficient fan capability. A space of approximately 2.5 inches or higher between the fans and the bench floor should be allowed so that air flow is not impeded.
- Sequential steps for Turn-On/Turn Off of Power Supplies.
 - 1. Turn on Driver power supply PS_1 (14V via JP1).
 - 2. Then, turn on MOSFET supply (PS_2) and slowly increase to 40V (via JP2).
 - 3. While monitoring the RF power from power meter and output waveform of the Drain, ramp up MOSFET power supply (PS_2) to the values per Table 2 making sure that output is stable for each supply voltage before proceeding to the next higher voltage.
 - 4. To turn-off, turn power supplies off in the reverse order.
- If RF output waveform, Vds and/or RF power level from power meter fluctuate, immediately shut down of PS_2 for safety and determine fault before resuming test.

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PERFORMANCE

a. Data summary

No\Para.	PS HV (V)	Id (A)	Pin (W)	Pout (W)	H (%)	Vds (V)
1	100	1.1	110.00	104	94.5	276
2	110	1.19	130.90	124	94.7	
3	120	1.3	156.00	149	95.5	
4	130	1.4	182.00	175	96.2	
5	140	1.51	211.40	204	96.5	
6	150	1.63	244.50	235	96.1	
7	160	1.75	280.00	268	95.7	
8	170	1.87	317.90	303	95.3	
9	180	2	360.00	342	95.0	
10	190	2.13	404.70	383	94.6	
11	200	2.25	450.00	424	94.2	576
12	210	2.4	504.00	472	93.7	
13	220	2.52	554.40	515	92.9	
14	230	2.66	611.80	564	92.2	
15	240	2.8	672.00	615	91.5	
16	250	2.95	737.50	669	90.7	
17	260	3.09	803.40	723	90.0	
18	270	3.23	872.10	775	88.9	
19	280	3.38	946.40	830	87.7	
20	290	3.52	1,020.80	882	86.4	
21	300	3.66	1,098.00	940	85.6	
22	320	3.7	1,155.00	1000	86.1	925

Table 2. Power Sequencing Data Summary

Table 2 shows the effects of varying the PS HV on MOSFET current, RF power, efficiency, and peak Vds. Efficiency vs. Pout is shown in Figure 2 and peak Vds vs. PS HV is shown in Figure 3. The efficiency is calculated using RF power output and DC input power of the power MOSFET. Efficiency remains higher than 94% up to RF power of 500W and 90% up to 800W. At RF output power of 1KW, the efficiency is reduced slightly to approximately 86%.

Figure 3 shows that the peak drain voltage (Vds) is approximately 3 times the PS HV voltage. This is close to the ideal value of 3.5 times PS HV voltage.

Figure 4 shows that the peak Vds is 276V when the PS HV voltage is 100V. Figure 5 shows that a peak Vds of 576V is achieved with a PS HV voltage setting of 200V. Figure 6 shows that a peak Vds of 876V is achieved with a PS HV voltage setting of 300V.

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b. Chart of data sheet

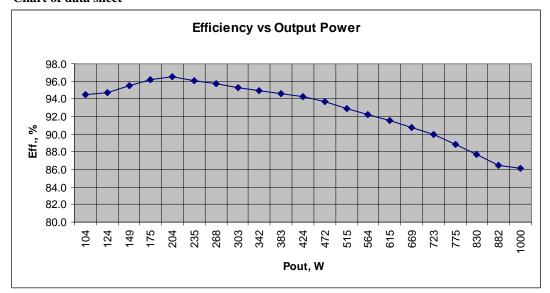


Figure 2. Efficiency vs. Pout

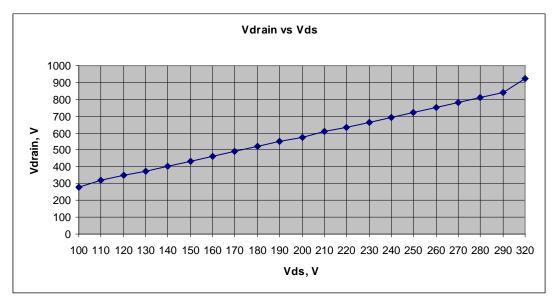


Figure 3. Vds vs. HV

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c. Waveform at MOSFET Drain for various settings of the HV PS

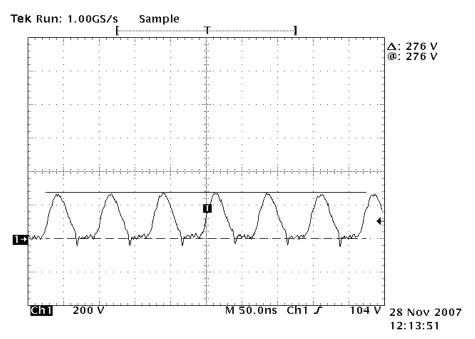


Figure 4. Peak VDS (PS HV = 100V)

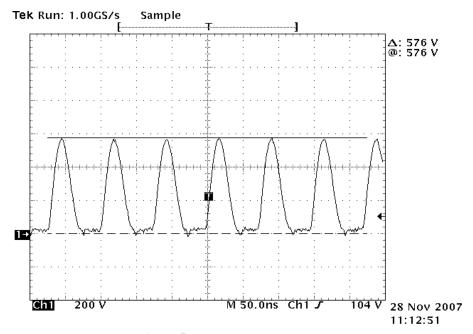


Figure 5. Peak VDS (PS HV = 200V)

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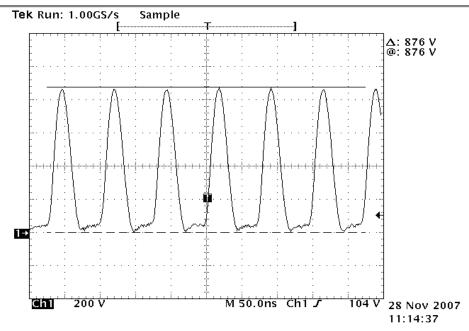


Figure 6. Peak VDS (PS HV = 300V)

CONCLUSIONS

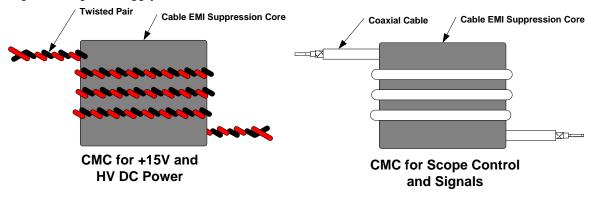
This application note is for a reference design using a DRF1200 as a CLASS-E RF generator. The high performance DRF1200 Hybrid was used because it includes both the driver, Power MOSFET, and bypass capacitors optimized to reduce inductance and achieve a single low-cost solution. A reference design board is available to demonstrate this high efficiency, 1KW, 13.56MHz RF generator with 86% efficiency using a drain supply voltage up to 320Vdc.

The critical aspects such as the layout of components for efficient power generation, testing, and air cooling requirements are also discussed.

Test Setup

It is highly recommended that a Common Mode Choke (CMC) is used on all power and measurement inputs and outputs. This approach provides the best stability and the most accurate measurements.

Construction of CMC's are illustrated below. The CMC on the left should be used for PS 1 and the PS 2 inputs. These lines are tightly twisted pairs (5-8 twists per inch). The CMC on the right should be used for the Scope Probe Cable. Three to five turns on each is sufficient. The CMC's should be placed as close to the DRF1200/CLASS-E Board as practical. Bench test pictures are included where Fair-Rite part number 0431164181 has been used in three places for power supply isolation.



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Appendix I. Overall Schematic

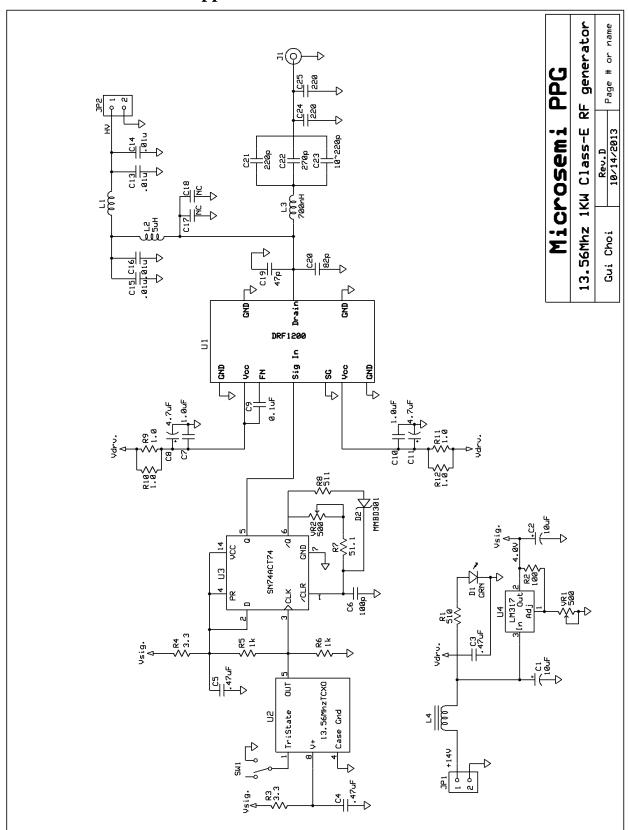


Figure 7. Overall schematic

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Appendix II. PCB Layout

PCB size: 3.5W * 7.5L in inch

PCB: FR-4, 65mil T

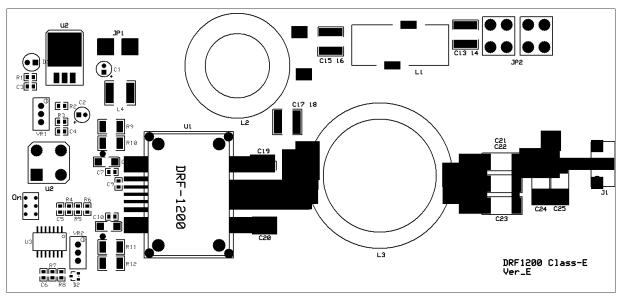


Figure 8. PCB Layout

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Appendix III. Parts List

No. RF MOSFET Hybrid 13B Microsemi Digi-key 1912 1019-key 1912 1019-key 1912 1019-key		Appendix III. I al is List							
C1 10µF/35V	Part ID		Size	Supplier	Supplier PN		Manuf. PN		
C2 10UF/16V S*11 Mouser 140-KRL16V10-RC Xicon 140-KRL16V10-RC C3 47UF/50V 0805 Digi-key 490-3328-1-ND GRM218F71H474KA88L C5 47UF/50V 0805 Digi-key 490-3328-1-ND GRM218F71H474KA88L C6 100FF50V 0805 Digi-key 490-3328-1-ND GRM218F71H474KA88L C6 100FF50V 0805 Digi-key S87-1438-1-ND Taiyo Yuden GMK2128J10SKG-T C8 47.0F35V 6032-28 Digi-key 478-1717-1-ND Taiyo Yuden GMK2128J10SKG-T C9 0.1UF 0805 Digi-key 587-1438-1-ND Taiyo Yuden GMK2128J10SKG-T C10 1.0UF/50V 0805 Digi-key 587-1438-1-ND Taiyo Yuden GMK2128J10SKG-T C11 4.7UF35V 6032-28 Digi-key 478-1717-1-ND Taiyo Yuden GMK2128J10SKG-T C11 4.7UF35V 6032-28 Digi-key 478-1717-1-ND Taiyo Yuden GMK2128J10SKG-T C11 4.7UF35V 6032-28 Digi-key 478-1717-1-ND Taiyo Yuden GMK2128J10SKG-T C11 0.01UF/1KV Cer. Disc Newark 18M6914 C14 0.01UF/1KV Cer. Disc Newark 18M6914 C15 0.01UF/1KV Cer. Disc Newark 18M6914 C16 0.01UF/1KV Cer. Disc Newark 18M6914 C17 C18 NC C18 NC C19 47PF/2500V 3838 ATC 700C470JW2500X ATC 700C470JW2500X C20 82PF/2500V 3838 ATC 700C470JW2500X ATC 700C470JW2500X C20 82PF/2500V 3838 ATC 100E221KW3600X ATC 100E	U1	RF MOSFET Hybrid	T3B	Microsemi	DRF1200	Microsemi	DRF1200		
C3	C1	10uF/35V	1812	Digi-key	pcc2183ct-nd				
C4	C2	10uF/16V	5*11	Mouser	140-XRL16V10-RC	Xicon	140-XRL16V10-RC		
C4	C3	.47uF/50V	0805	Digi-key	490-3328-1-ND		GRM21BR71H474KA88L		
C5	C4	· · · · · · · · · · · · · · · · · · ·	0805				GRM21BR71H474KA88L		
C6 100pF/S0V		<u>'</u>							
C7									
C8						Taivo Vuden	GMK212B1105KG-T		
C90							diimelebataana i		
C10			_	Digi Koy	110 1111 1 145	Taivo Vuden	UMK212B7104KC-T		
C11 4.7uF35V 6032-28 Digl-key 478-1717-1-ND				Digi-kov	E07_1430_1_ND				
C13						raiyo ruueii	GIMKE12B3103KG-1		
C14									
C15									
C16									
C17									
C18			Cer. Disc	Newark	18М6914				
C19									
C20 B2PF/2500V 3838 ATC 700C820JW2500X ATC 700C820JW2500X C21 220PF/3600V 3838 ATC 100E221kW3600X ATC 100E221kW3600X C22 270PF/3600V 3838 ATC 100E Series									
C21 220PF/3600V 3838 ATC 100E221KW3600X ATC 100E221KW3600X C22 270PF/3600V 3838 ATC 100E27IKW3600X ATC 100E22IKW3600X C24 220PF/3600V 3838 ATC 100E22IKW3600X ATC 100E22IKW3600X C25 220PF/3600V 3838 ATC 100E22IKW3600X ATC 100E22IKW3600X R1 5100hm/1/8W 0805 Digl-key P510ATR-ND Panasonic ERJ-6GEYJ511V R2 1000hm 1/8W 0805 Digl-key P510ATR-ND Panasonic ERJ-6GEYJ3R3V R3 3.30hm 1/8W 0805 Digl-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R4 3.30hm 1/8W 0805 Digl-key P1.00KCCT-ND Panasonic ERJ-6GEYJ3R3V R5 1.0K ohm 1/8W 0805 Digl-key P1.00KCCT-ND Panasonic ERJ-6ENF101V R6 1.0K ohm 1/8W 0805 Digl-key P51.1CCT-ND Panasonic ERJ-6ENF5101V R8									
C22 270PF/3600V 3838 ATC 100E271KW3600X ATC 100E271KW3600X C23 10~220PF 3838 ATC 100E Series C24 220PF/3600V 3838 ATC 100E221KW3600X ATC 100E221KW3600X C25 220PF/3600V 3838 ATC 100E221KW3600X ATC 100E221KW3600X R1 5100hm/1/8W 0805 Digi-key P510ATR-ND Panasonic ERJ-6GEYJ511V R2 1000hm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R4 3.30hm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-6GEYJ3R3V R5 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-ERF1001V R6 1.0K ohm 1/8W 0805 Digi-key P51.10CT-ND Panasonic ERJ-ENF1001V R7 51.10hm 1/8W 0805 Digi-key P51.0CT-ND Panasonic ERJ-ENF5101V R8 5110hm 1/2W Axial Digi-key		<u> </u>							
C23 10~220pF 3838 ATC 100E Series C24 220PF/3600V 3838 ATC 100E221KW3600X ATC 100E221KW3600X R1 510ohm/1/8W 0805 Digi-key P510ATR-ND Panasonic ERJ-6GEYJ511V R2 100ohm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R4 3.3ohm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R5 1.0K ohm 1/8W 0805 Digi-key P1.0DKCCT-ND Panasonic ERJ-6GEYJ3R3V R8 1.0K ohm 1/8W 0805 Digi-key P1.0DKCCT-ND Panasonic ERJ-6GEYJ3R3V R8 1.0K ohm 1/8W 0805 Digi-key P1.0DKCCT-ND Panasonic ERJ-6GEYJ3R3V R8 1.0K ohm 1/8W 0805 Digi-key P1.0DKCCT-ND Panasonic ERJ-6GEYJ3R3V R8 1.1km 1/2W 0805 Digi-key P1.0DKCCT-ND Panasonic ERJ-6GEYJ3R3V R8 1.1km 1/2W Axial<		· · · · · · · · · · · · · · · · · · ·				ATC	100E221KW36ooX		
C24 220PF/3600V 3838 ATC 100E221KW3600X ATC 100E221KW3600X C25 220PF/3600V 3838 ATC 100E221KW3600X ATC 100E221KW3660X R1 5100hm/1/8W 0805 Digi-key P510ATR-ND Panasonic ERJ-6GEYJ3F1IV R2 1000hm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R4 3.3ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-6GEYJ3R3V R5 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-6GEYJ3R3V R6 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-6FNF1001V R7 51.1ohm 1/8W 0805 Digi-key P51.1CCT-ND Panasonic ERJ-6ENF51R1V R8 511ohm 1/2W Axial Digi-key P51.0CT-ND Panasonic ERJ-6ENF51R1V R9 1ohm 1/2W Axial Digi-key P1.0BCT-ND Panasonic ERD-51TJ1R0V R					100E271KW3600X	ATC	100E271KW36ooX		
C25 220PF/3600V 3838 ATC 100E221KW3600X ATC 100E221KW3600X R1 5100hm1/38W 0805 Digi-key P510ATR-ND Panasonic ERJ-6GEVJS11V R2 100chm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEVJ3R3V R4 3.3ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-6GEVJ3R3V R5 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-6EFV3R3V R6 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-6ENF51001V R7 51.1ohm 1/8W 0805 Digi-key P51.1CCT-ND Panasonic ERJ-6ENF51R1V R8 5110hm 1/2W Axial Digi-key P51.0CT-ND Panasonic ERJ-6ENF51R1V R9 1ohm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-6ENF51R1V R1 1ohm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-51TJ1R0V	C23		3838	ATC	100E Series				
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R2 1000hm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R3 3.30hm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R5 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-ENF1001V R6 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-ENF1001V R7 51.1ohm 1/8W 0805 Digi-key P51.1CCT-ND Panasonic ERJ-ENF1001V R8 511ohm 1/8W 0805 Digi-key P51.1CCT-ND Panasonic ERJ-6ENF51R1V R9 1ohm 1/2W Axial Digi-key P51.1CCT-ND Panasonic ERJ-6ENF51R1V R10 1ohm 1/2W Axial Digi-key P51.CCT-ND Panasonic ERD-5ENF51R1V R11 1ohm 1/2W Axial Digi-key P1.0BRCT-ND Panasonic ERD-5ITJ1R0V R11 1ohm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-SITJ1R0V	C25	220PF/3600V	3838	ATC	100E221KW3600X	ATC	100E221KW36ooX		
R2 1000hm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R3 3.30hm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R5 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-ENF1001V R6 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-ENF1001V R7 51.10hm 1/8W 0805 Digi-key P5.11CCT-ND Panasonic ERJ-ENF101V R8 5110hm 1/8W 0805 Digi-key P5.11CCT-ND Panasonic ERJ-ENF511V R9 10hm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-S1TJ1R0V R10 10hm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-S1TJ1R0V R11 10hm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-S1TJ1R0V R12 10hm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-S1TJ1R0V <td< td=""><td>R1</td><td>510ohm/1/8W</td><td>0805</td><td>Digi-key</td><td>P510ATR-ND</td><td>Panasonic</td><td>ERJ-6GEYJ511V</td></td<>	R1	510ohm/1/8W	0805	Digi-key	P510ATR-ND	Panasonic	ERJ-6GEYJ511V		
R4 3.30hm 1/8W 0805 Digi-key P3.3ACT-ND Panasonic ERJ-6GEYJ3R3V R5 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-ENF1001V R6 1.0K ohm 1/8W 0805 Digi-key P1.00KCCT-ND Panasonic ERJ-ENF1001V R7 51.10hm 1/8W 0805 Digi-key P51.1CCT-ND Panasonic ERJ-6ENF51R1V R8 5110hm 1/8W 0805 Digi-key P51.1CCT-ND Panasonic ERJ-6ENF5111V R9 10hm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-517J1R0V R10 10hm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-517J1R0V R11 10hm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-517J1R0V R12 10hm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-517J1R0V R11 10hm 1/2W Axial Digi-key P1.0BBCT-ND Panasonic ERD-517J1R0V	R2	100ohm 1/8W	0805	-					
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ST 12AWG	13	Toroid Inductor		Micrometals		Micrometals	T225-6 5		
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L4 2T 18AWG Digikey A5857R-100-ND Alpha 5857 RD005 U2 13.56 MHz Osc Half Allied Elec. EP1100HSTSC-13.56M Ecliptek Co. EP1100HSTSC-13.560M	1.4	Toroid Inductor		Allied Elec.		Fair-Rite	2643540302		
U2 13.56 MHz Osc Half Allied Elec. EP1100HSTSC-13.56M Ecliptek Co. EP1100HSTSC-13.560M	L4	2T 18AWG			I				
	U2		Half						
	U3	Dual Flip-Flop IC	14SOP	Digi-key	296-13131-1-ND	TI	SN74ACT74NSR		

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